

become long-term Plant employees, transcending changes in Federal oversight organizations and transitions in contractors.

Demands on the Plant and the workers were high, given the requirements of the Cold War. Work was difficult, production schedules were challenging, and the work environment was often hot, loud, dirty, and laden with noxious fumes. The security demands of the Cold War also affected worker awareness of hazards in that, prior to 1989, documents discussing many aspects of operations were classified and, at the direction of line management and AEC security, detailed knowledge of work activities was based on a “strict need to know.” The workers’ sense of loyalty and service would also translate into acceptance of these security policies and the expectation that they would be told everything that they needed to know.

From the 1950s to the 1990s, government oversight of ES&H elements of PGDP contractor activities evolved. The primary offices of the Federal regulatory organizations for the diffusion plants — the AEC, ERDA, and DOE — have always been located in Oak Ridge, although there was a Federal presence at PGDP for most of the period 1952 to 1990. Records indicate AEC involvement in collaborative research activities related to radiation and health physics in the 1950s through the 1970s, but there is little evidence of direct observation of, or direction to, the PGDP contractor regarding ES&H, which was not an uncommon practice for a regulatory agency during that period. Carbide provided quarterly progress reports to the AEC summarizing operational, maintenance, construction, industrial hygiene, health physics, and accident data and analysis and responded to information requests on health physics issues. However, the interactions between the contractor and AEC clearly emphasized maintaining or increasing production. In the 1970s, as new environmental regulations were enacted, there is evidence of growing involvement by the Commonwealth of Kentucky and OR in site activities and in the effects of site activities on the environment and the public. In the 1980s, increased DOE oversight was evidenced by additional ES&H inspections by the local site office and OR. On September 18, 1985, then-Secretary of Energy John Herrington announced that DOE-wide environmental surveys would be conducted; the PGDP survey occurred in November and December 1987. These surveys led to changes in DOE and contractor ES&H programs. However, the 1990 DOE Tiger Team identified ineffective DOE oversight and unclear oversight roles and responsibilities as key management findings.

2.2 Operations

Although major construction activities would continue through 1956, Union Carbide began hiring approximately 1,700 permanent Plant workers in 1951. The first process buildings, C-331, C-333, C-310, and C-315, were completed and started operation in September 1952, and the first product was withdrawn in November. The purpose of the gaseous diffusion plant has been and continues to be the enrichment of uranium, initially for military applications and subsequently for commercial reactor fuel. PGDP enriches feed material in the form of UF_6 gas with approximately 0.7 percent uranium-235 to UF_6 with one to three percent uranium-235. The enriched product from PGDP was sent to other DOE sites at Portsmouth or Oak Ridge for further enrichment. Most UF_6 feed material came from the depleted tails produced during normal diffusion operations at PGDP and from Oak Ridge and Portsmouth. From 1952 through 1977, UF_6 feed material was also produced from uranium trioxide or UO_3 (called “yellowcake”) at PGDP in Buildings C-410 and C-420; this feed material was supplied by sources such as El Dorado Mining and Refining, Mallinckrodt Chemical Works, and General Chemicals (now Allied Chemical) and comprised less than 10 percent of the UF_6 fed to the cascade. From 1953 through 1964 and intermittently from 1968 through 1977, the feed plant also produced UF_6 from UO_3 from spent reactor fuel processed at the Hanford and Savannah River sites. After 1977, all feed came in the form of UF_6 from outside sources such as Oak Ridge, Portsmouth, and Allied Chemical.

Although natural uranium is not a highly radioactive material, it is toxic, both chemically and radiologically, when inside the body. The uranium exposure pathway of greatest hazard at PGDP was inhalation of uranium dust. Feed material was made from production reactor tails from 1953 until 1964, and intermittently from 1968 to 1977. The percentage of PGDP cascade feed material from reactor tails averaged 19 percent during the 19 years this material was used, ranging from 3 percent in 1975 to 65 percent in 1973. Processing of UO_3 into UF_6 was accomplished in three steps: reduction, hydro-fluorination, and fluorination (see Figure 3).

Reduction involved transforming UO_3 into UO_2 (commonly referred to as “black oxide”) using hydrogen gas. Hydro-fluorination of UO_2 into UF_4 (commonly referred to as “green salt”) was accomplished by adding anhydrous hydrofluoric acid (HF). Fluorination was

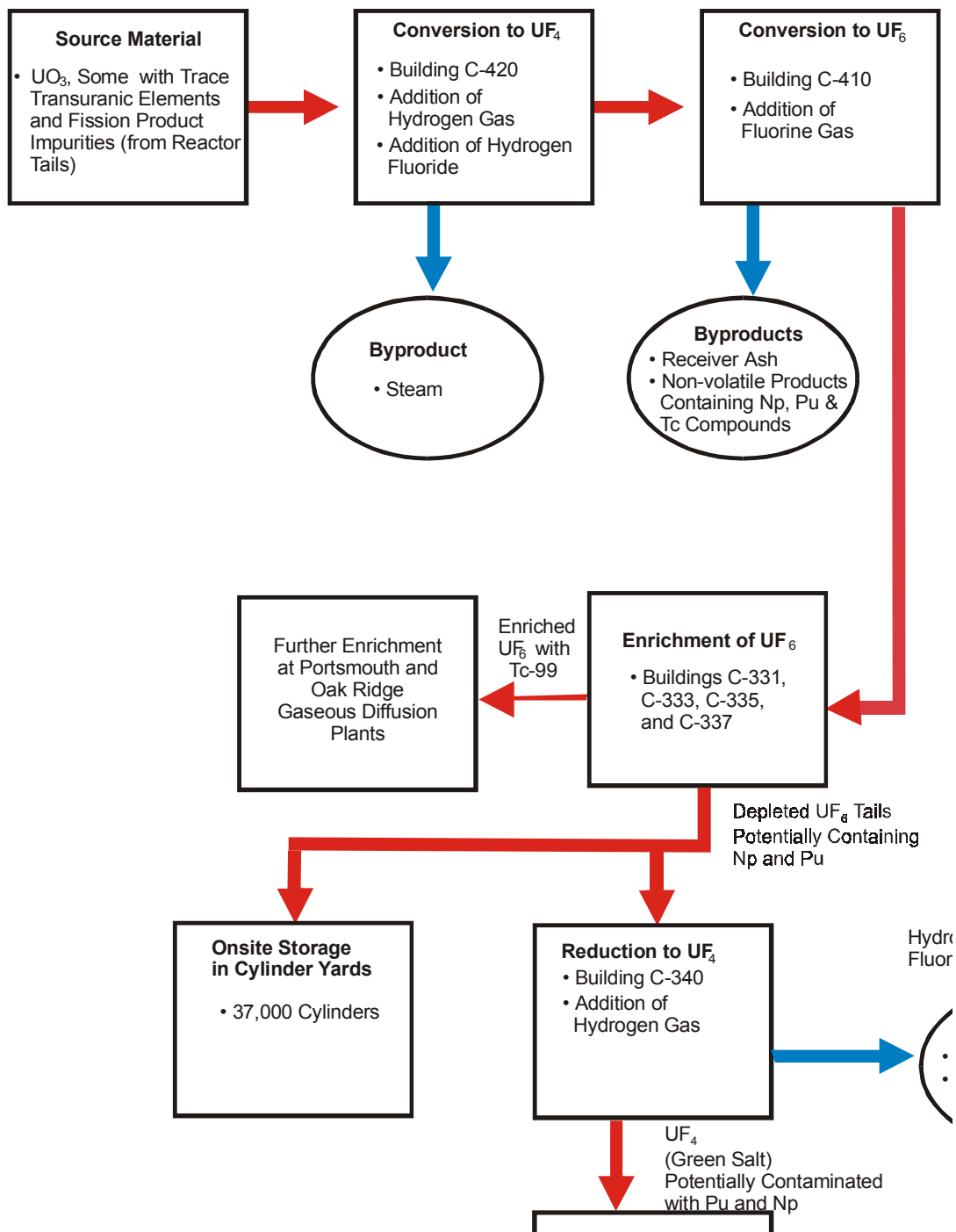


Figure 3. Historical Uranium Enrichment Process

conducted in C-410 using heated elemental fluorine gas in tower reactors. The first two steps were performed in C-410 on vibration tray reactors (shaker trays) from 1953 to 1956. In 1956, due to frequent equipment failures, spills, leaks, and the increased demand for feed, Building C-420 (commonly called the “green salt” plant) was completed and green salt production at C-410 was phased out. In C-420, the reduction was performed in two-stage fluidized bed reductors; the hydro-fluorination was performed in three sets of horizontal screw reactors or in a two-stage fluidized bed hydro-fluorinator. Working conditions in C-410 and C-420 were hot and loud; surface areas were coated with yellowcake, green salt, black oxide, and airborne uranium dust. High radiation areas existed near the fluorination towers and ash receivers. Respirators were specified for most work activities, but compliance was inconsistent. The feed plant was shut down in 1977.

Major Facilities at PGDP

- *C-331, C-333, C-335, and C-337 – Gaseous Diffusion Process Buildings*
- *C-410/420 – UF₆ Feed Plant*
- *C-300 – Central Control Building*
- *C-310 – Purge and Product Withdrawal*
- *C-315 – Surge and Waste Building*
- *C-340 – Metals Plant*
- *C-400 – Cleaning Building*

The main process buildings at PGDP (C-331, C-333, C-335, and C-337) contain the “cascades,” which are a series of compressor and converter stages and supporting equipment arranged in cells and units that progressively enrich the UF₆ feed. Enrichment occurs as the UF₆ passes through barriers in the converters allowing isotopes of lower molecular weight to pass through. The series of converters results in two streams, or cascades, of UF₆; one of progressively higher-percentage uranium-235 that moves to the product withdrawal station in C-310, and one of progressively lower-percentage uranium-238 that moves toward the tails withdrawal station in C-315. Both the enriched product and the depleted tails are fed into cylinders and allowed to cool until solid, with the product shipped to Portsmouth and the depleted material either re-fed to the cascade or stored on site. The process building work areas were hot, but clean, except during

maintenance or modification activities that required system entry. The process buildings were also the source of several major explosions, fires, and UF₆ releases and frequent smaller releases during connection and disconnection of sample bottles and feed and product cylinders. Generally, personal protective equipment (PPE) was only specified for maintenance or non-routine work activities.

In 1957, the presence of neptunium-237 and technetium-99 at PGDP was documented, and between 1959 and 1966 numerous studies related to the behavior, health effects, and controls for these elements were conducted by the Paducah Health Physics and Hygiene Department and the AEC. The percentage of transuranics, such as neptunium and plutonium, and fission products, such as technetium, in the reactor tails material was very small, estimated at approximately 0.2 parts per million (ppm) neptunium, 4 parts per billion plutonium, and 7 ppm technetium. However, these elements are much more hazardous than natural uranium and were concentrated by the cascade at certain specific locations, presenting increased hazards to certain workers. Neptunium has a specific activity up to 2,000 times greater than an equivalent amount of uranium, depending on the level of enrichment. Plutonium is significantly more radioactive than neptunium, but constituted a lesser hazard because it was present in much lower concentrations. Both plutonium and neptunium are significant radiation hazards if inhaled or ingested. Technetium is primarily a beta emitter with a higher specific activity than uranium, and is highly mobile in groundwater.

Approximately 25 percent of the neptunium in the feed material remained in the feed plant as dust or ash. Approximately 50 percent remained in cylinder heels after feeding, and approximately 25 percent was vaporized in the cascade, plating out toward the upper end of the cascade. Technetium tended to migrate to the top of the cascade, and much was drained off into the product or vented to the atmosphere. In 1958, a neptunium recovery process was initiated in C-400 to recover neptunium from the fluorination ash and cylinder heels for classified uses. In response to a demand for technetium for use at Oak Ridge, a program to recover technetium from the cylinder wash water and raffinate (e.g., solvents) from neptunium recovery operations began in April 1960. Due to the concentrated quantities of these materials, the recovery operations presented additional radiation protection problems requiring special protective measures. Air samples collected from areas contaminated with neptunium indicate the potential for

high radiation doses to workers in these areas (e.g., reports of continuous sampling for February and March 1959 indicated an average of 10 and 27 dpm per m³ respectively in the neptunium recovery area in C-710). In September 1961, magnesium fluoride pellet traps were installed in the feed plant to capture neptunium and technetium; in January 1963, similar traps were installed at the C-310 product withdrawal stations. By March 1962, neptunium recovery operations had ended, and in June 1963, technetium recovery operations also ceased. A different technetium recovery process was initiated in the mid-1970s to remove technetium from aqueous waste streams for the purpose of environmental protection.



Aerial View of PGDP Circa 1952

Before the mid-1970s, a complex uranium recovery process was operated in C-400 for separating uranium from waste and scrap materials, concentrating it, and converting it to an oxide. The uranium recovery system was not leak-tight, and leaks were common. However, steps were taken to control operators' exposure to process materials. Routine surveys were conducted to monitor the concentration of radioactivity on surfaces and in the air in C-400, and the health physics staff recommended changes in work practices based on the results of these surveys. In the mid-1970s, the solvent extraction process for uranium recovery was replaced with a simpler precipitation and filtration process. The filtrate, containing low concentrations of radionuclides, was discharged to the environment via the C-400 drains. Sludges and filter cake were processed at PGDP for uranium recovery or sent to Fernald for recovery.

From December 1956 through December 1962 and from January 1968 through October 1973, PGDP produced UF₄ and uranium metal in C-340 for weapons uses. The uranium metal production process involved reducing UF₆ (normally from the tails cylinder) to UF₄

by combining it with hydrogen in a heated tower. The UF₄ was mixed with magnesium and fed into lined firing reduction vessels (commonly referred to as “bombs”), placed in furnaces, and heated until it fired into a metal ingot, called a “derby.” The derbies were removed from the bomb, cleaned, cut, and shipped to Oak Ridge. This process created a dusty environment in the metals plant with airborne UF₄ and magnesium powders, uranium metal oxides, radionuclide uranium daughter products, and magnesium fluoride dusts. The production of UF₄ continued until 1977, primarily to provide HF for feed operations. Working conditions were dirty, with airborne uranium and HF leaks. The use of army assault masks or respirators was specified for many metals plant activities, although workers did not always use them. The metals plant was responsible for much of the fluoride released to the environment at PGDP.

During the 1950s and 1960s, in order to retain certain skills and to maintain local employment levels after initial construction, a variety of non-enrichment work for other Federal agencies was performed. These activities included manufacturing missile components, superconducting electromagnets, and fuel shipping casks. In addition, until 1985, disassembly of weapons components and recovery of metals were performed at PGDP. While the work involved limited amounts of hazardous materials (e.g., lead), the primary exposure risk to workers on these projects was presented by normal Plant work activities in adjacent areas of the buildings. Nickel and aluminum recovery was performed in three smelters in C-746A; gold recovery occurred principally in the C-746A disassembly room and in C-400. Primary hazards in smelting operations were heat, working with molten metals, noxious fumes, and some potential for airborne radioactive contaminants.

2.3 Maintenance and Modifications

Much of the exposure to radioactive and hazardous materials at the PGDP resulted from system maintenance and improvement activities. The amount and complexity of equipment in continuous operation at high speeds, temperatures, and pressures resulted in frequent intrusions into piping systems to repair valves, compressors, motors, feed pulverizers and conveyors, and supporting piping and components. Opening of systems and components exposed residual UF₆ to moisture in the air, forming caustic HF gas and depositing uranium fluoride (UO₂F₂) around the immediate area. Changing of dust bag collection filters in process buildings